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RESEARCH MEMORANDUM

INVESTIGATION OF THE EFFECTS OF LEADING-EDGE
CHORD-EXTENSIONS ON THE AERODYNAMIC AND CONTROL
CHARACTERISTICS OF TWO SWEPTBACK WINGS AT MACH
NUMBERS OF 1.41, 1.62, AND 1.96

By Ellery B. May, Jr.

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A wind-tunnel investigation was made to evaluate the effects of small-span leading-edge chord-extensions on the longitudinal characteristics of two swept wings and on the control characteristics of flap-type and spoiler-type controls at Mach numbers of 1.41, 1.62, and 1.96. The wings had 51.7° leading-edge sweepback and incorporated 7-percent-thick biconvex and 6-percent-thick hexagonal airfoil sections with taper ratios of 0.615 and 0.625 and aspect ratios of 2.47 and 2.39, respectively.

The data indicated that small-span leading-edge chord-extensions, of the type found to be highly effective in improving the longitudinal stability of certain swept wings at subsonic speeds, could be left projected at supersonic speeds with no detrimental effects to the lift, drag, or pitching-moment characteristics. Addition of the extension did not influence the characteristics of the flap-type control to any noticeable degree but did appear to slightly improve spoiler effectiveness at positive angles of attack.

INTRODUCTION

The results of a low-speed investigation reported in reference 1 indicated that the use of small-span leading-edge chord-extensions could effectively eliminate the characteristic irregularities in the longitudinal stability of certain sweptback wings below maximum lift. The action of the device is presumably to eliminate or dissipate the vortex flow over the tip sections that is responsible for these irregularities (discussed, for example, in reference 2). The device has simpler

mechanical details and, in the cases tried, provided better low-speed lift-drag ratios than other types of leading-edge devices, such as flaps or slats. Accordingly, if no adverse aerodynamic effects are incurred by the presence of such a device at transonic and supersonic speeds, it would be permissible to leave the extension projected at all speeds, and the mechanical design would thus be greatly simplified.

The purpose of the present investigation is to evaluate at supersonic speeds the effects of small-span chord-extensions of the type described in reference 1 on the lift, drag, and pitching-moment characteristics of two swept wings and on the characteristics of flap-type and spoiler-type controls on these wings. The leading-edge sweepback of the wings, which was 51.7° , and the size and location of the chord-extensions were patterned after the configuration of the low-speed investigation reported in reference 1. The wings incorporated biconvex and hexagonal airfoil sections of 7 and 6 percent thickness, respectively, with aspect ratios of about 2.4. The chord-extensions had spans of 13 percent and 25 percent semispan and extended 15 percent of the wing mean aerodynamic chord ahead of the wing leading edge. The investigation was made at Mach numbers of 1.41, 1.62, and 1.96, for which cases the Mach lines lie ahead of, on, and behind the wing leading edge.

COEFFICIENTS AND SYMBOLS

C_L	lift coefficient $\left(\frac{\text{Lift}}{qS} \right)$
C_D	drag coefficient $\left(\frac{\text{Drag}}{qS} \right)$
C_m	pitching-moment coefficient $\left(\frac{\text{Pitching moment}}{qS\bar{c}} \right)$; pitching-moment reference axis shown in figures 2 and 3
$C_{l_{\text{gross}}}$	gross rolling-moment coefficient $\left(\frac{\text{Semispan wing rolling moment}}{2qSb} \right)$; reference axis shown in figures 2 and 3
q	free-stream dynamic pressure
S	exposed semispan wing area without chord-extensions
c	local wing chord

$\bar{c}$	mean aerodynamic chord of exposed wing without chord-extension
A	aspect ratio (b^2/S')
b	wing span (twice distance from fuselage axis to wing tip)
S'	wing area (including area blanketed by the fuselage)
α	angle of attack measured with respect to free stream
δ	control-surface deflection measured in a plane perpendicular to hinge axis
h	height of spoiler above wing surface
R	Reynolds number based on mean aerodynamic chord of exposed wing
M	Mach number

DESCRIPTION OF MODELS

A photograph of the model arrangement is shown as figure 1. The geometric details of the leading-edge chord-extensions and the wing models are shown in figures 2 and 3. The chord-extensions which were symmetrical about the chord plane, protruded $0.15\bar{c}$ ahead of the wing leading edge and had spans of $0.13b/2$ and $0.25b/2$. For both spans, the inboard end of the extension was located at the same spanwise position.

Both semispan wing models had 51.7° sweepback of the leading edge. The wing that incorporated 7-percent-thick, biconvex airfoil sections (fig. 2) had an aspect ratio of 2.47 and a taper ratio of 0.615 and will be referred to as the biconvex wing. The biconvex wing was equipped with a $0.50b/2$ spoiler-type control which was located on the $0.65c$ line and extended from $0.45b/2$ to $0.95b/2$. The wing that incorporated 6-percent-thick hexagonal airfoil sections (fig. 3) had an aspect ratio of 2.39 and a taper ratio of 0.625 and will be referred to as the hexagonal wing. The hexagonal wing had a $0.25c$ trailing-edge-flap-type control which extended from $0.43b/2$ to $0.95b/2$. In addition, the hexagonal wing had a spoiler-type control which was identical in percent span and percent chord location as the spoiler on the biconvex wing.

TUNNEL AND TEST TECHNIQUE

The Langley 9- by 12-inch supersonic blowdown tunnel is a non-return type tunnel utilizing the compressed air of the Langley 19-foot

pressure tunnel. The absolute stagnation pressure of the air ranges from 2 to $2\frac{1}{3}$ atmospheres. In order to insure condensation-free flow in the test section, the air is passed through a silica gel dryer and then through banks of finned electrical heaters. Turbulence-damping screens are located in the settling chamber. The three test section Mach numbers are provided by interchangeable nozzle blocks.

Extensive calibration measurements and schlieren photographs with the tunnel clear indicate that satisfactory flow conditions exist in the test section at all three Mach numbers. The following table lists the maximum recorded deviations in calibration measurements taken at numerous positions in the test section with the tunnel clear; properties of the conditioned air are also included:

Average Mach number Variables	1.41	1.62	1.96
Deviation in Mach number	±0.02	±0.01	±0.02
Deviation in ratio of static to stagnation pressure, percent	2.0	1.3	2.2
Deviation in stream angle, deg	±0.25	±0.20	±0.20
Maximum dewpoint temperature, °F	20	-5	-20
Minimum stagnation temperature, °F	120	125	165

With the fuselage used in this investigation mounted in the test section, static-pressure measurements were taken in the region normally occupied by the wing. The measurements indicated that, at a Mach number of 1.41, a weak disturbance from the reflected fuselage bow wave would intersect the aft portion of the wing; however, this disturbance caused a change of less than 0.04 in Mach number and only a negligible change in dynamic pressure.

The test setups are similar to those reported in references 3 and 4. The semispan models are cantilevered from a five-component strain-gage balance. The balance and fuselage rotate with the wing as the angle of attack is changed. The aerodynamic forces and moments are measured with respect to the balance axes and are rotated to the wind axes of the model. The semispan wing models are tested in the presence of but are not attached to a half-fuselage which is shimmed out 0.25 inch from the tunnel wall to minimize wall-boundary-layer effects. A 0.02-inch

clearance gap existed between the wing and the fuselage. Further discussion of the test technique is reported in references 4 and 5.

ACCURACY OF DATA

No tare corrections have been applied to the data to account for leakage around the gap between the wing and the fuselage. Minor asymmetrical conditions in the lift, rolling-moment, and pitching-moment data were caused by small errors in fabrication and model setup. Misalignment between the wing-chord plane and the fuselage axis was less than $\pm 0.03^\circ$ for all of the configurations. For the spoiler tests, the angles of attack were not always duplicated and deviations from the nominal values amounted to as much as $\pm 0.05^\circ$. Static calibration indicated no measurable change in control-surface deflection caused by control-surface loading.

RESULTS AND DISCUSSION

Longitudinal Characteristics

The lift, drag, and pitching-moment data for the biconvex and hexagonal wings with and without leading-edge chord-extensions are presented in figures 4 and 5, respectively. Within the range of this investigation, which covered subsonic and supersonic leading-edge conditions, addition of the $0.13b/2$ or $0.25b/2$ chord-extension to each wing caused an increase in lift approximately in proportion to the increase in wing area, (figs. 4(a) and 5(a)) and shifted the wing center of pressure forward less than 1 percent of the wing mean aerodynamic chord (figs. 4(b) and 5(b)). The drag polars (figs. 4(c) and 5(c)), except for some increase in the values of lift-drag ratio at the higher lift coefficients, were essentially unaffected by addition of the chord extensions. These data indicate that leaving the device extended would have no detrimental effect on the aerodynamic characteristics of swept-back wings of the type investigated.

It is interesting to note that the same type of inflection occurred in the lift curves at a Mach number of 1.41, and to some extent at a Mach number of 1.62 (figs. 4(a) and 5(a)) as occurred in the lift curves of the biconvex wing of reference 1 at low subsonic speeds. For the low-speed investigation, this inflection was found to be caused by the formation of a vortex along the wing leading edge. The data of the present investigation are insufficient to determine whether the lift inflection is associated with the same sort of flow at supersonic speeds when the wing leading edges are subsonic. In the investigation of

reference 6, a similar type inflection was observed and studied in some detail; however, the similarity is perhaps fortuitous since for that investigation the wing leading edge was supersonic.

Control Characteristics

The data for evaluating the effects of the $0.13b/2$ chord-extension on the control characteristics of flap-type and spoiler-type controls are presented in figures 6 and 7. It should be pointed out that the rolling-moment data have been presented as the gross rolling moment for the semispan wing in order that spanwise center of pressure could be determined if desired. The lateral control effectiveness is given by the variation of gross rolling moment with control deflection. For the configurations investigated, addition of the chord-extension did not influence the characteristics of the flap-type control to any noticeable degree (fig. 6). It did appear, however, to slightly improve the spoiler-type control effectiveness at positive angles of attack, as evidenced by the increased slopes of the curves of lift and rolling moment plotted against control projection (figs. 7(a) and 7(b)) and in the more nearly linear variations of pitching moment with control projection (fig. 7(c)).

A comparison was made of the relative effectiveness of spoilers for the two wings without chord-extensions, and the data have been presented in figure 8. The spoiler appears to be more effective when used on the wing with biconvex airfoil sections.

CONCLUDING REMARKS

An investigation has been made at Mach numbers of 1.41, 1.62, and 1.96 to evaluate the effects of small-span leading-edge chord-extensions on the longitudinal characteristics of two sweptback wings and on the characteristics of flap-type and spoiler-type controls. Addition of small-span extensions to either wing increased the lift in approximately the same proportion as the increase in area, and moved the wing center of pressure forward less than 1 percent of the wing mean aerodynamic chord. The lift-drag ratios were essentially unaffected. Addition of the $0.13b/2$ extension did not influence the characteristics of the flap-type control to any noticeable degree but did appear to improve slightly spoiler-type control effectiveness at positive angles of attack. Thus,

it appears that leaving the device extended has no detrimental effect in the subsonic or supersonic speed range. The effects in the transonic range are yet to be determined.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va.

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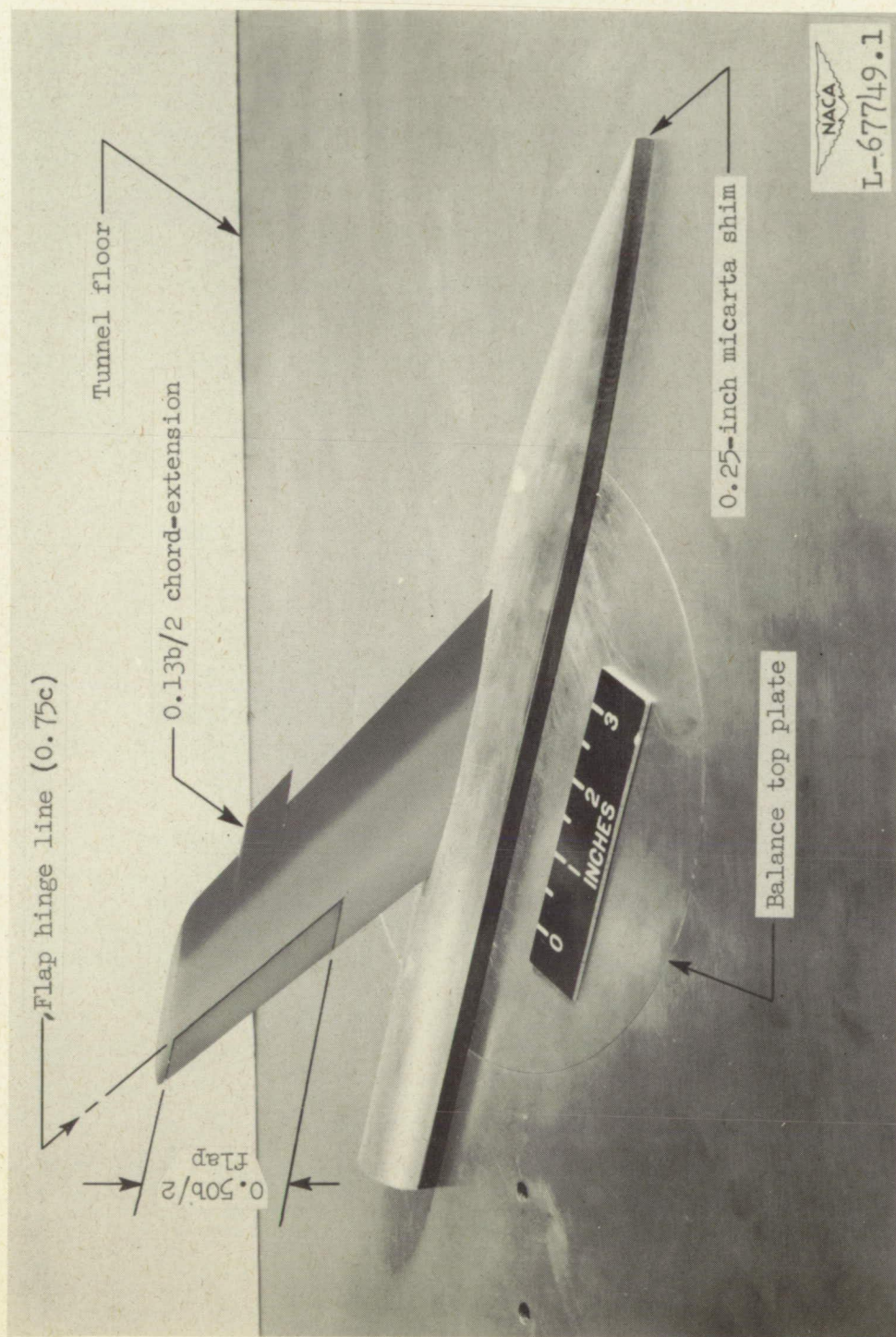


Figure 1.- Photograph of hexagonal wing showing model arrangement.

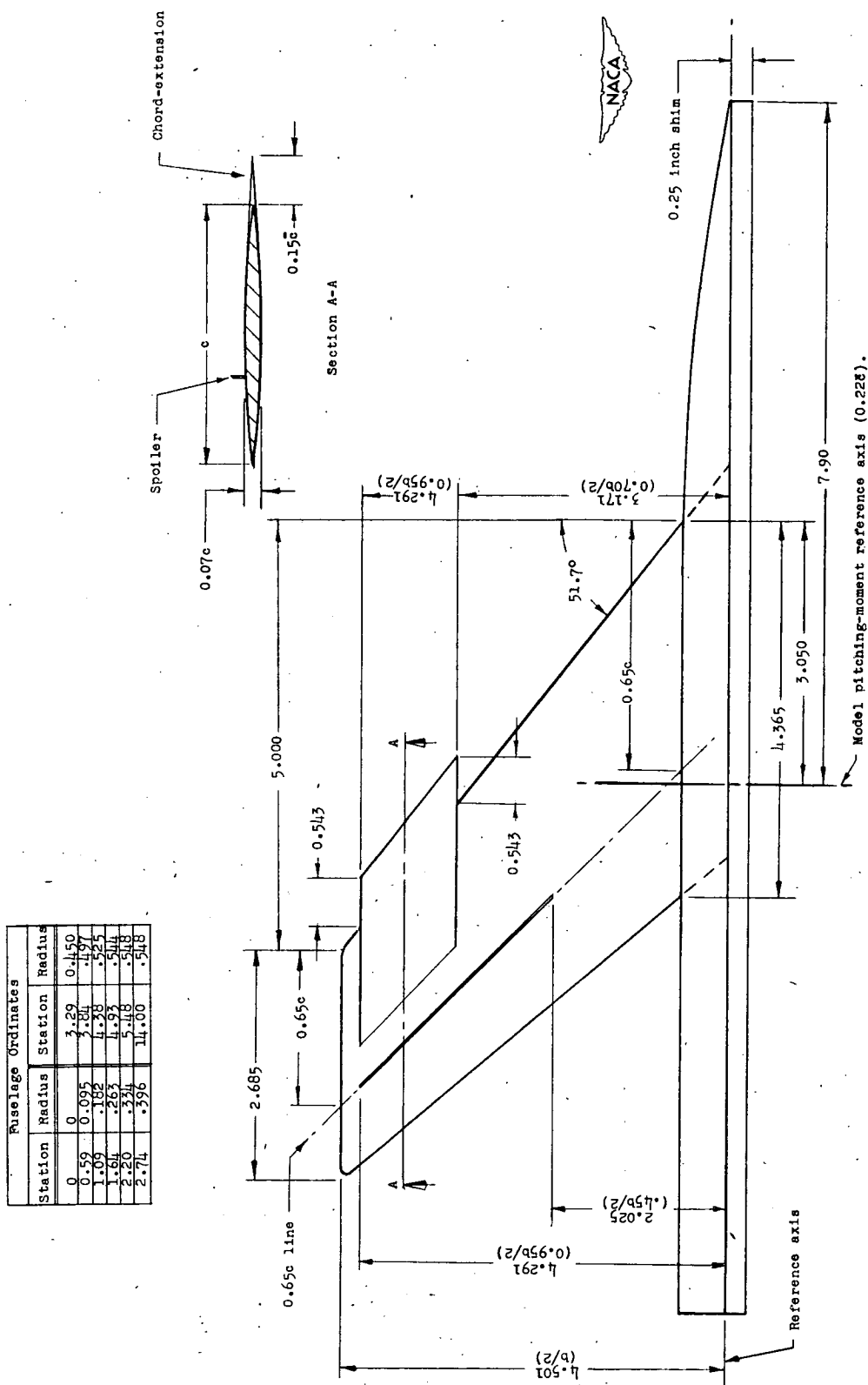


Figure 2.- Details of wing model with 0.07t/c biconvex airfoil sections. Mean aerodynamic chord, 3.6l; span, 9.002. Shown with 0.25b/2 chord-extension and 0.06h/c spoiler. All dimensions in inches.

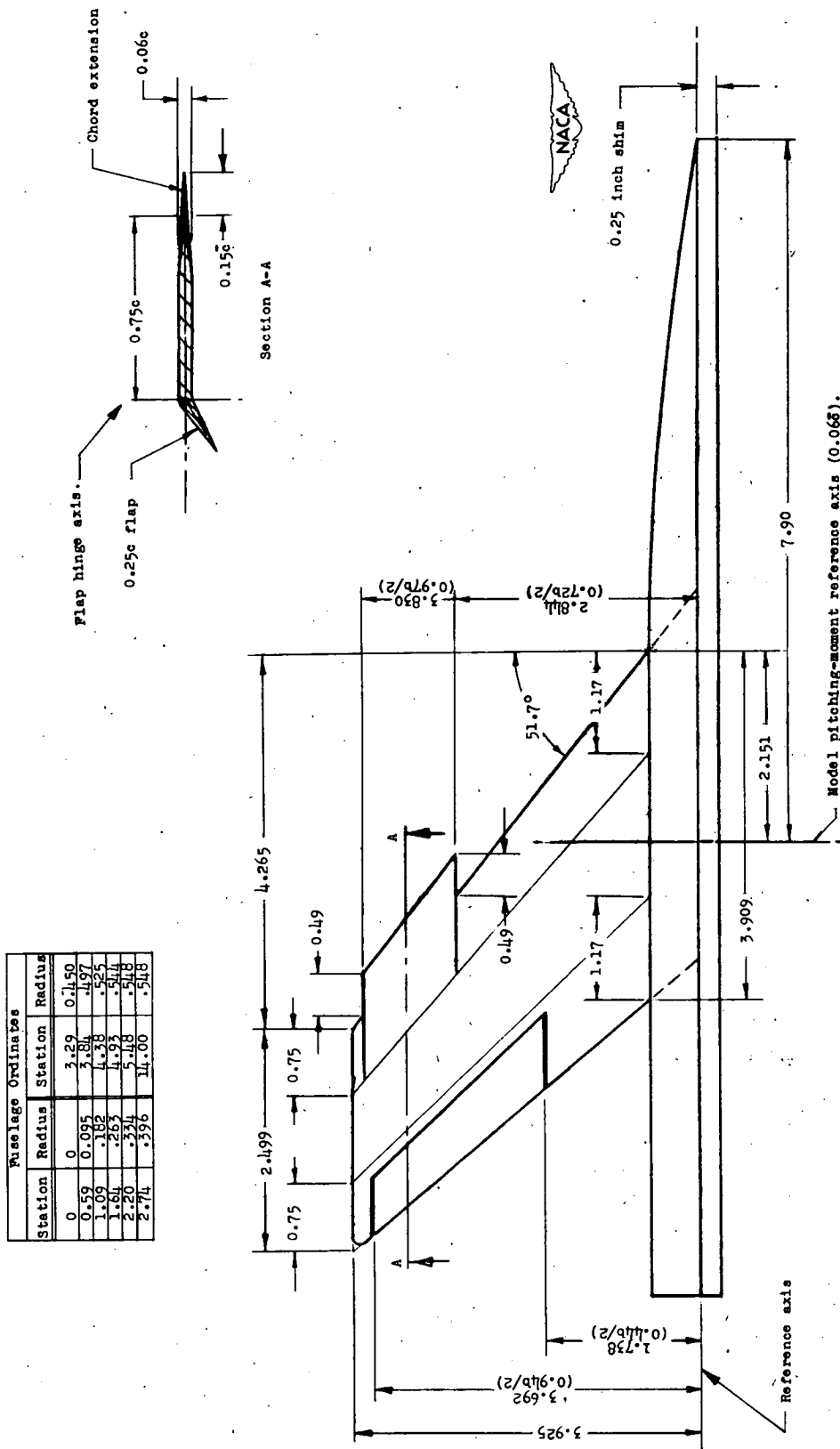


Figure 3.- Details of wing with 0.06t/c hexagonal airfoil sections. Mean aerodynamic chord, 3.27; span, 7.850. Shown with 0.25b/2 chord extension and 0.25c trailing-edge control. All dimensions in inches.

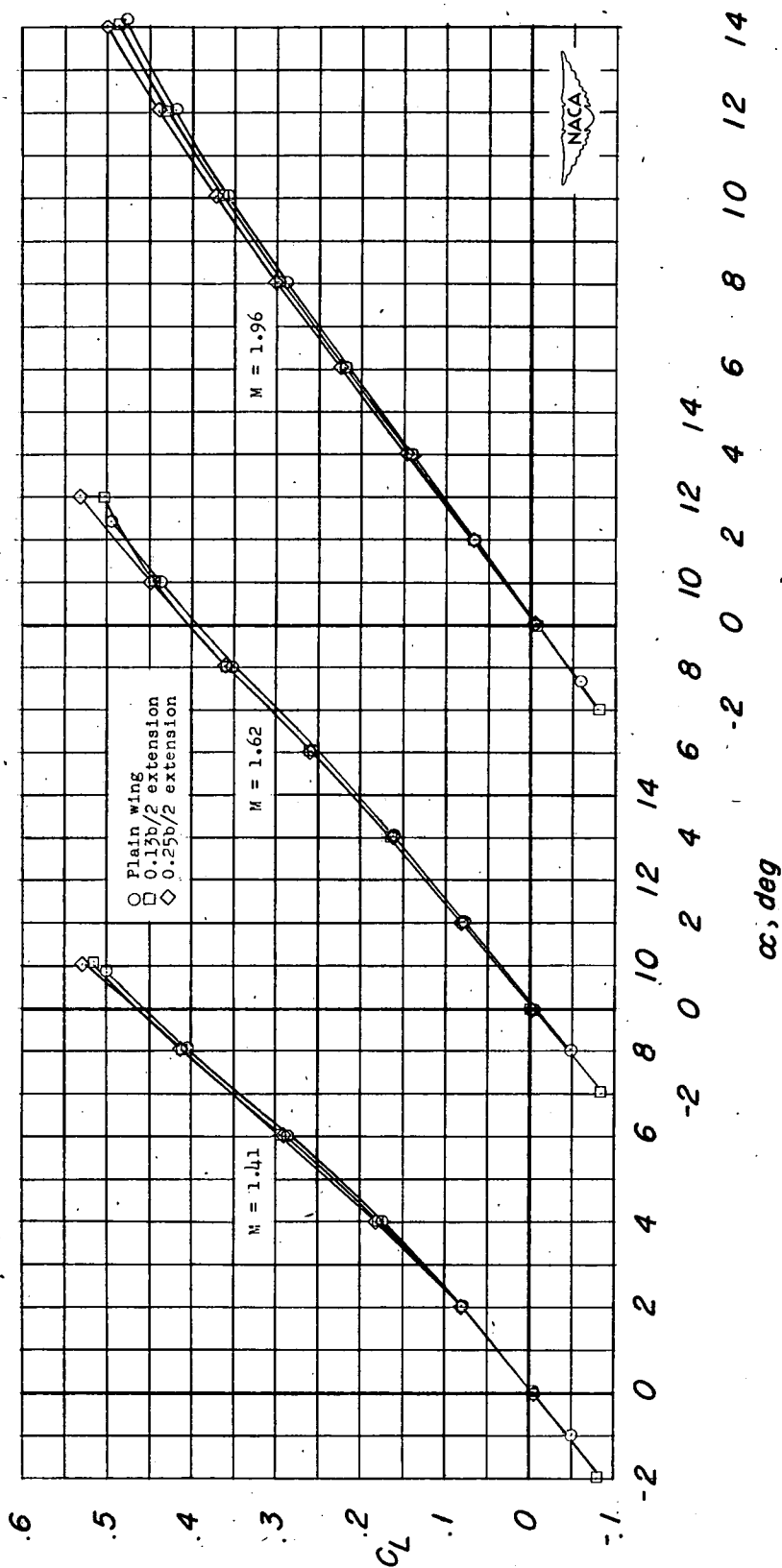
(a) Variation of C_L with α .

Figure 4.- The effects of leading-edge chord-extensions on the aerodynamic characteristics of a wing with biconvex airfoil sections having 51.7° leading-edge sweepback. $M = 1.41$, 1.62 , and 1.96 ; $R = 2.0 \times 10^6$, 1.8×10^6 , and 1.7×10^6 , respectively.

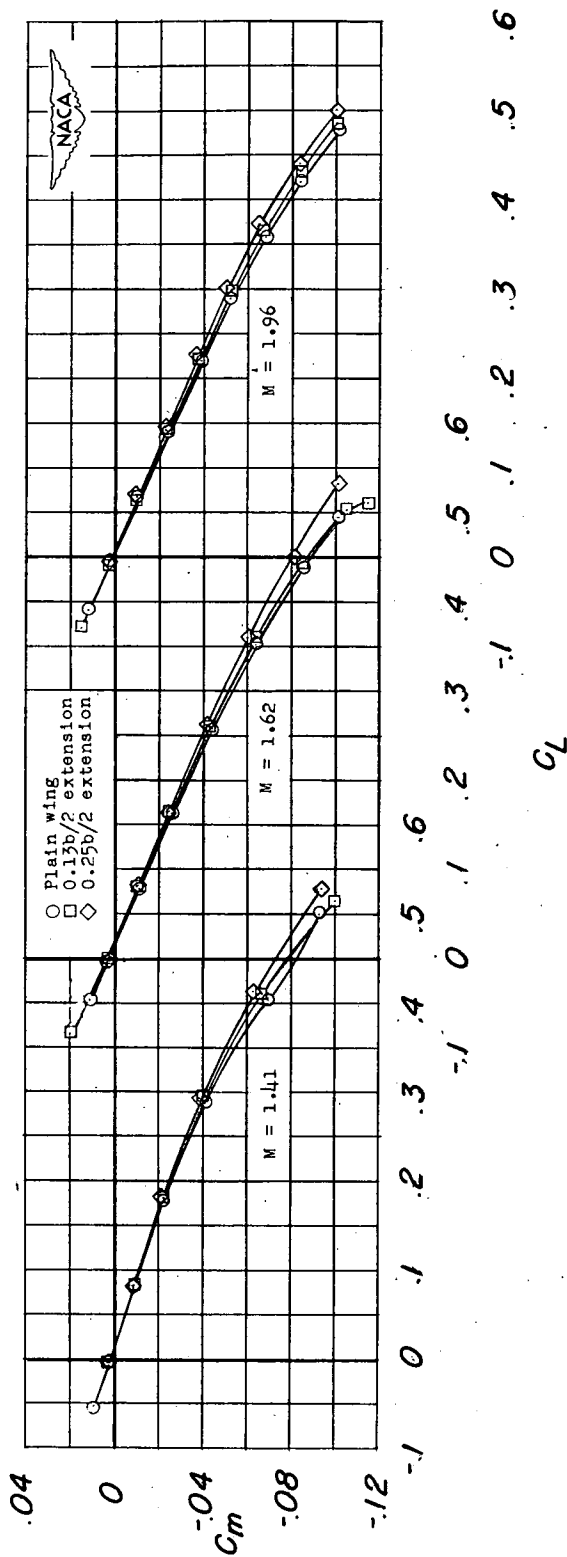
(b) Variation of C_m with C_L .

Figure 4.- Continued.

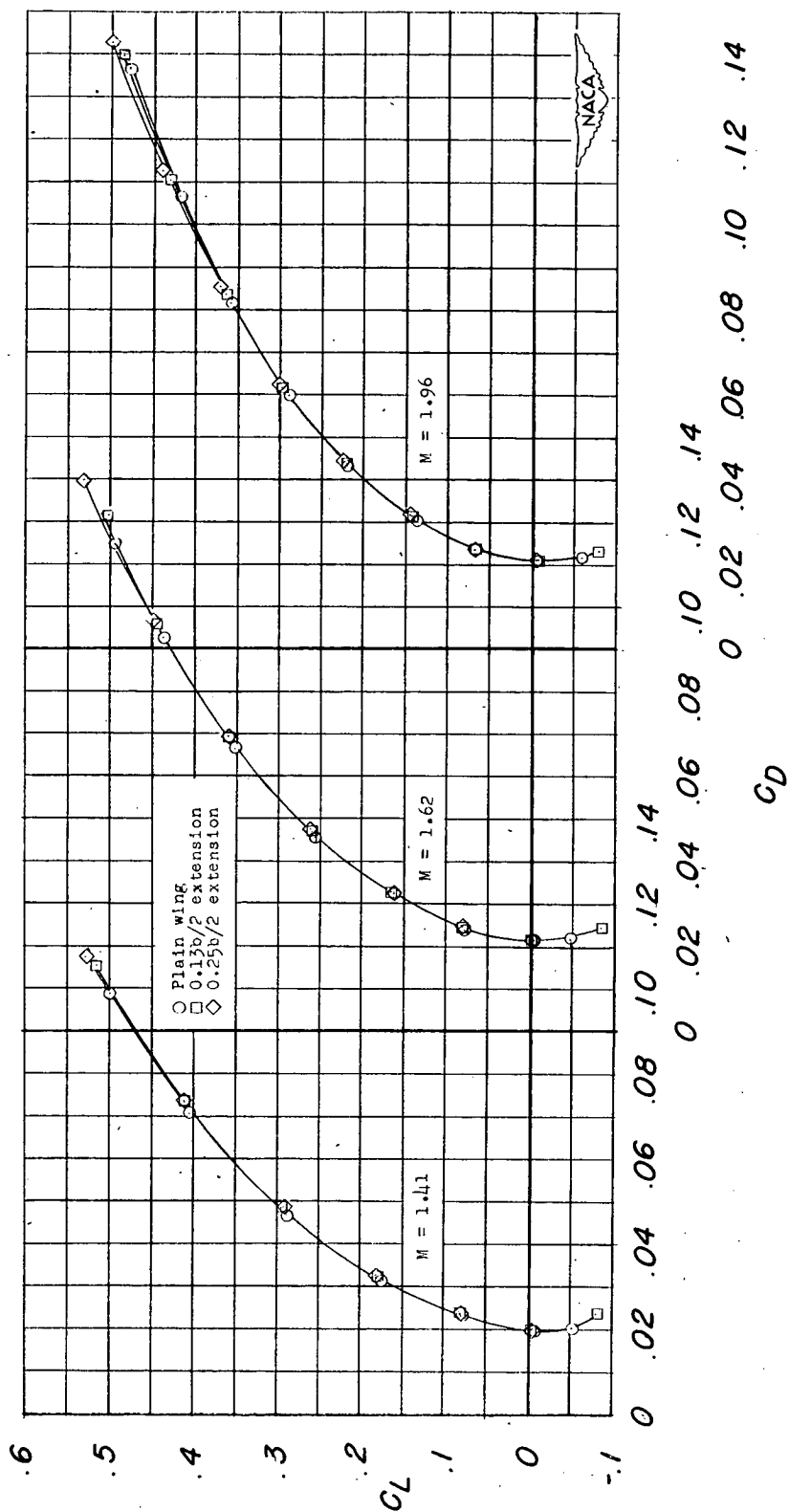
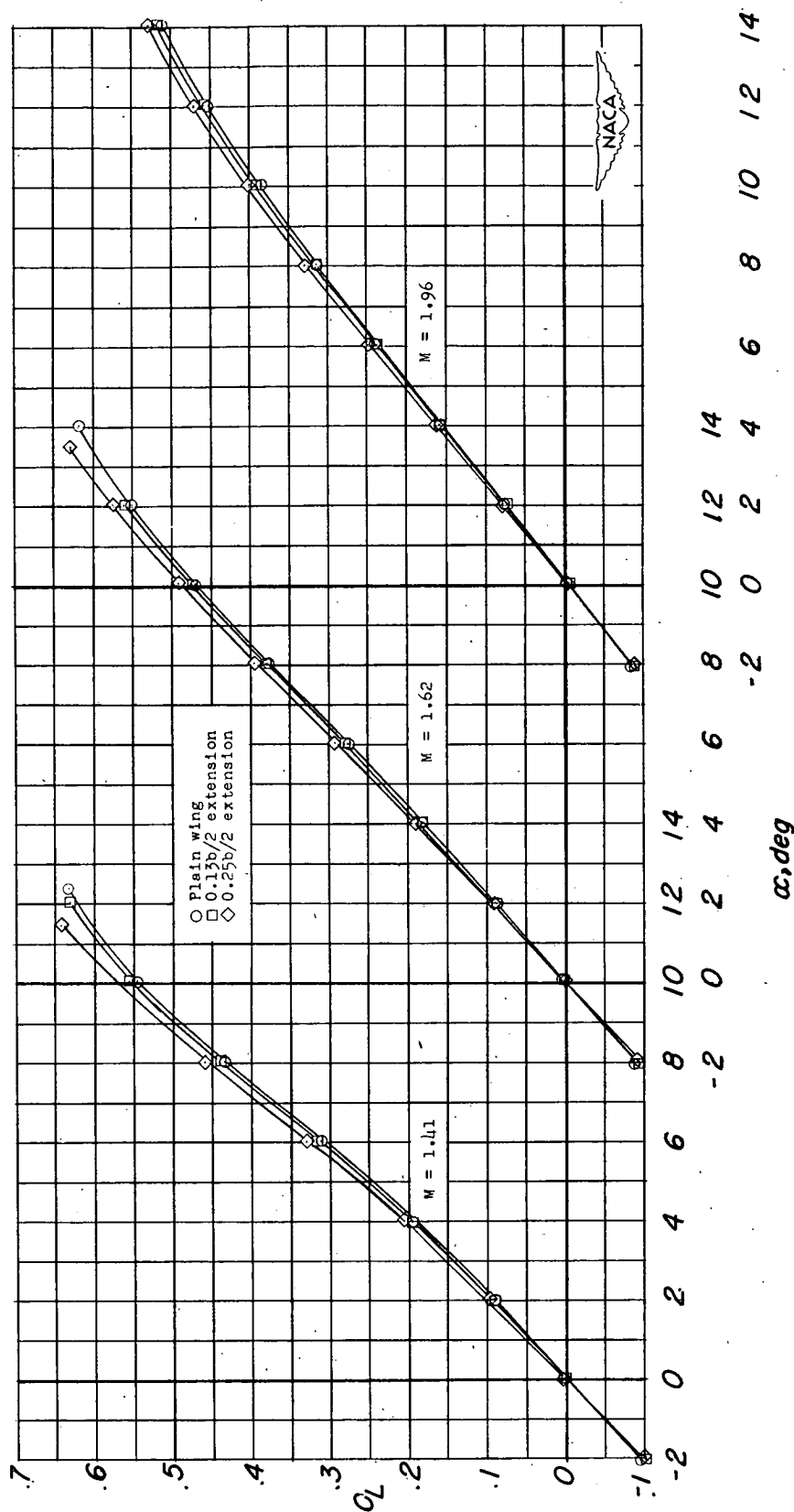
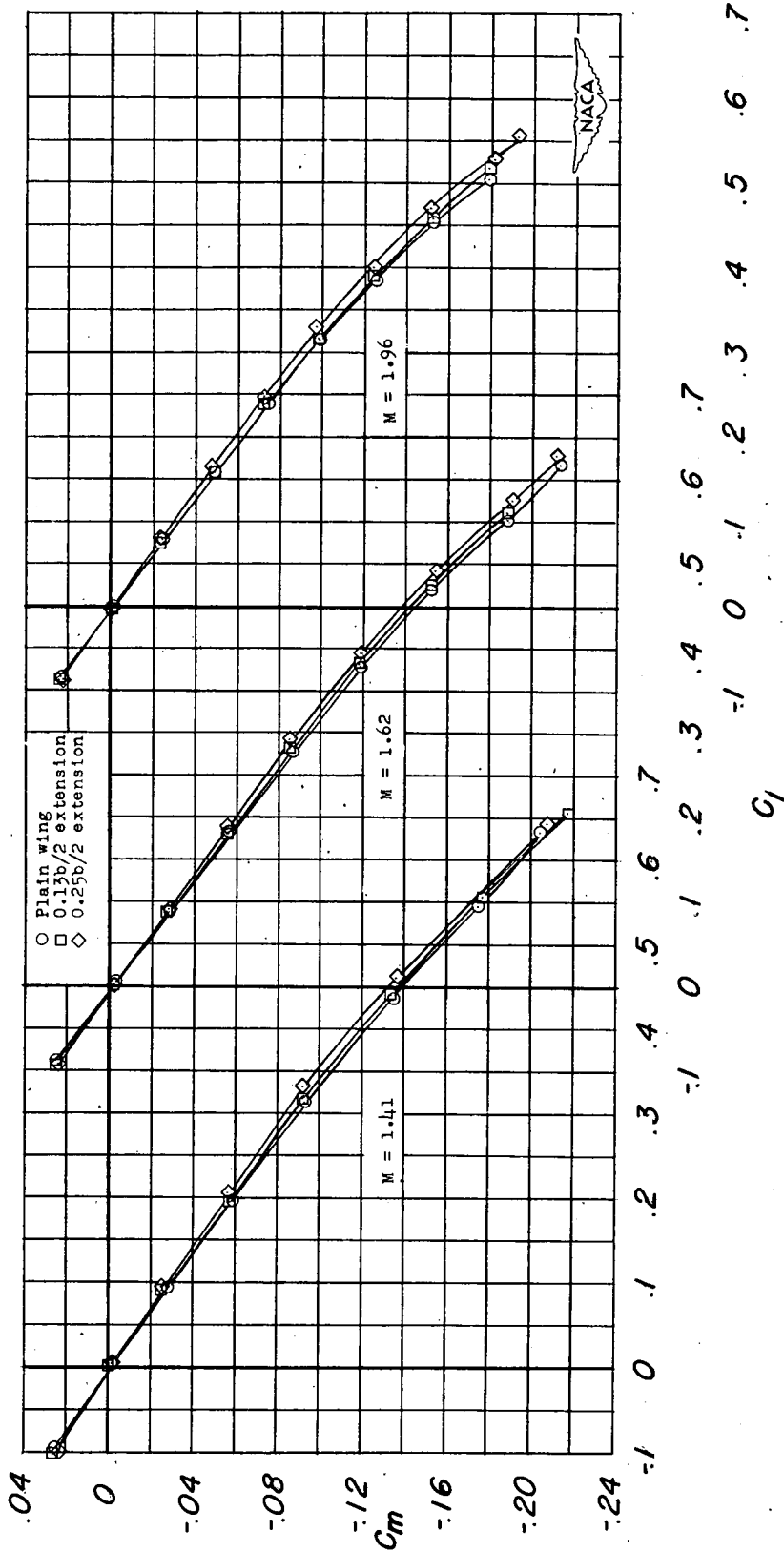
(c) Variation of C_L with C_D .

Figure 4.- Concluded.



(a) Variation of C_L with α .

Figure 5.- The effects of leading-edge chord-extensions on the aerodynamic characteristics of a wing with hexagonal airfoil sections having 51.7° leading-edge sweepback. $M = 1.41$, 1.62, and 1.96; $R = 2.0 \times 10^6$, 1.8×10^6 , and 1.7×10^6 , respectively.



(b) Variation of C_m with C_L .

Figure 5.- Continued.

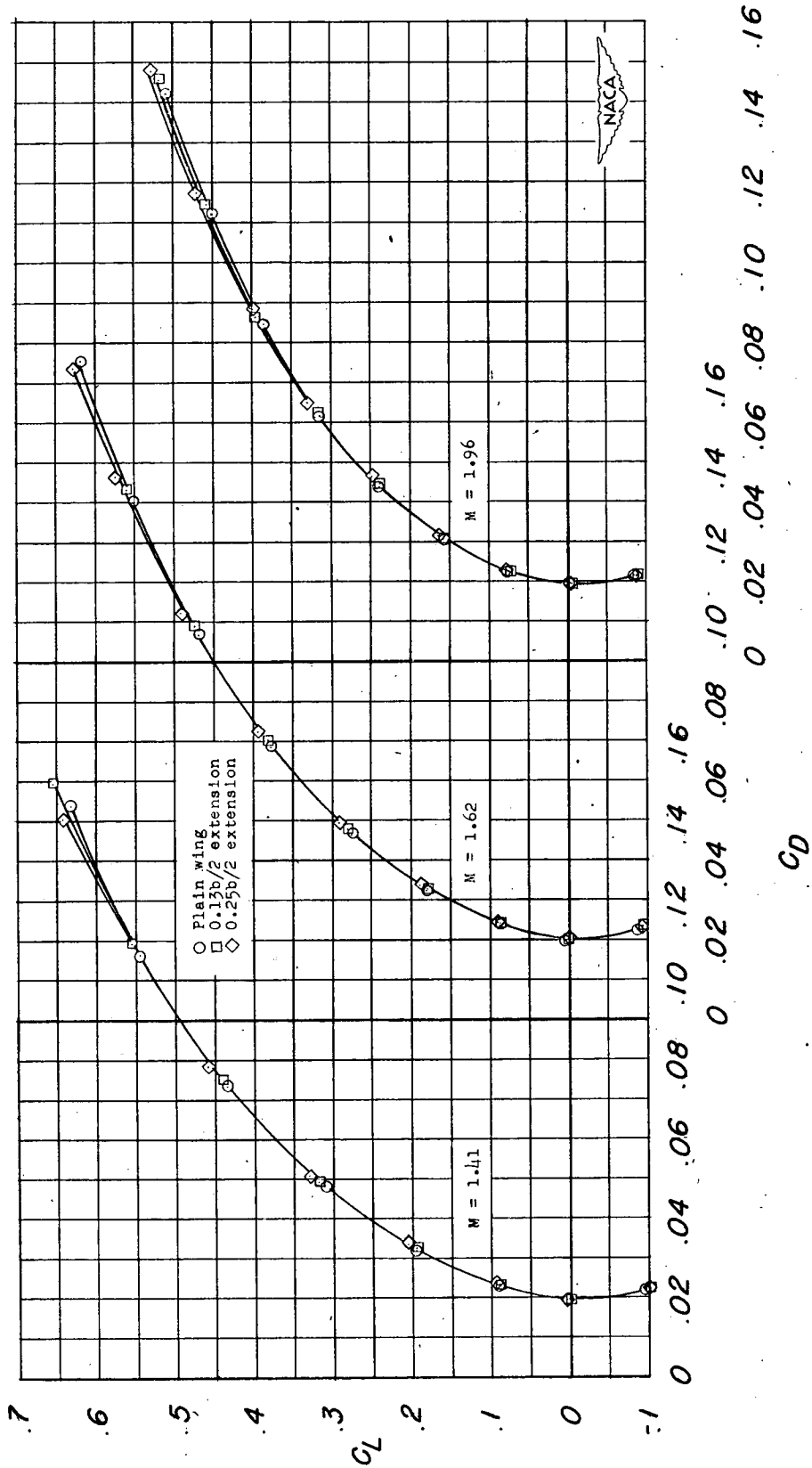
(c) Variation of C_L with C_D .

Figure 5.- Concluded.

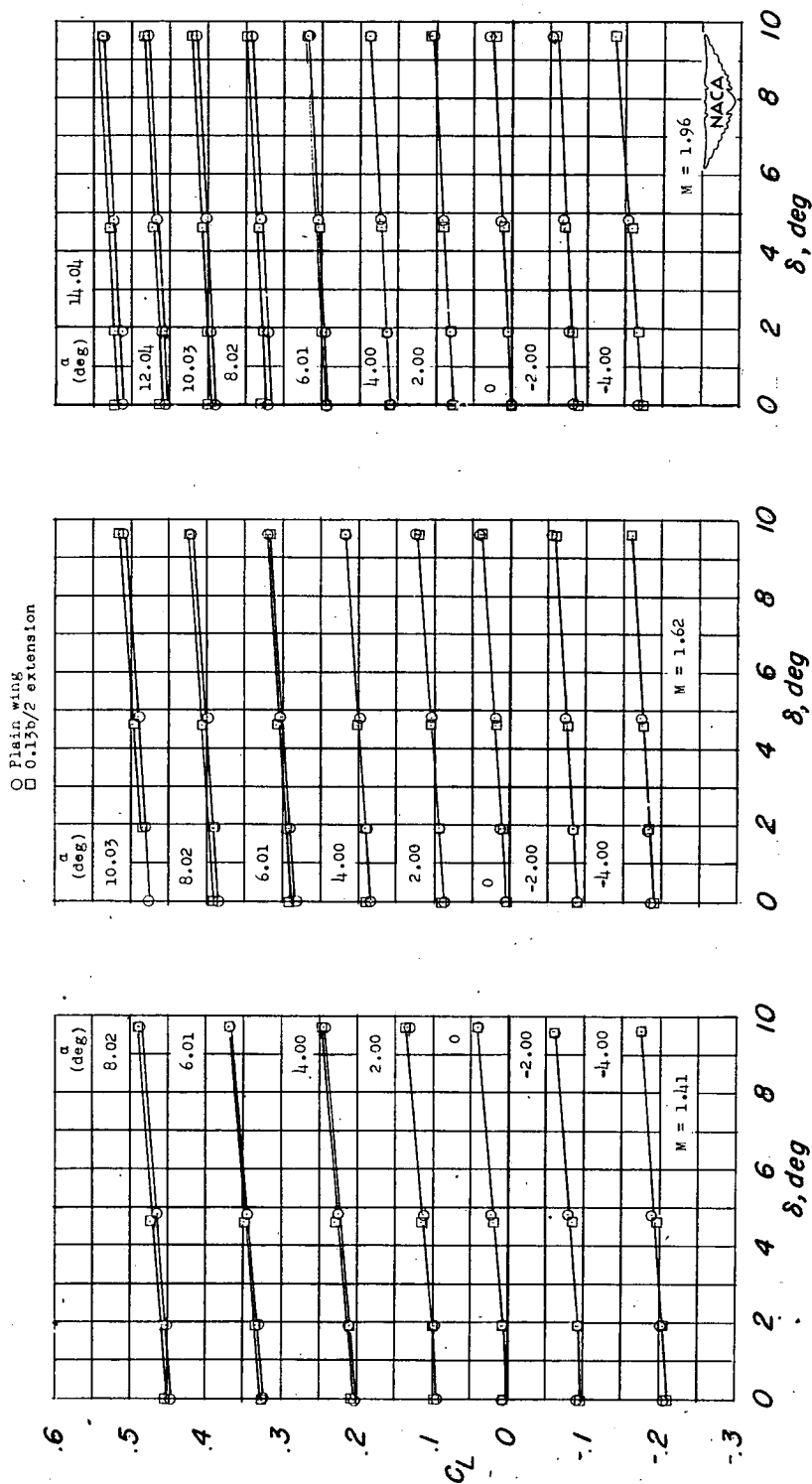
(a) Variation of C_L with δ .

Figure 6.- The effects of a 0.13b/2 leading-edge chord-extension on the control characteristics of a 0.25c, 0.50b/2 trailing-edge flap-type control on a hexagonal wing with 51.7° leading-edge sweepback. $M = 1.41$, 1.62, and 1.96. $R = 2.0 \times 10^6$, 1.8×10^6 , and 1.7×10^6 , respectively.

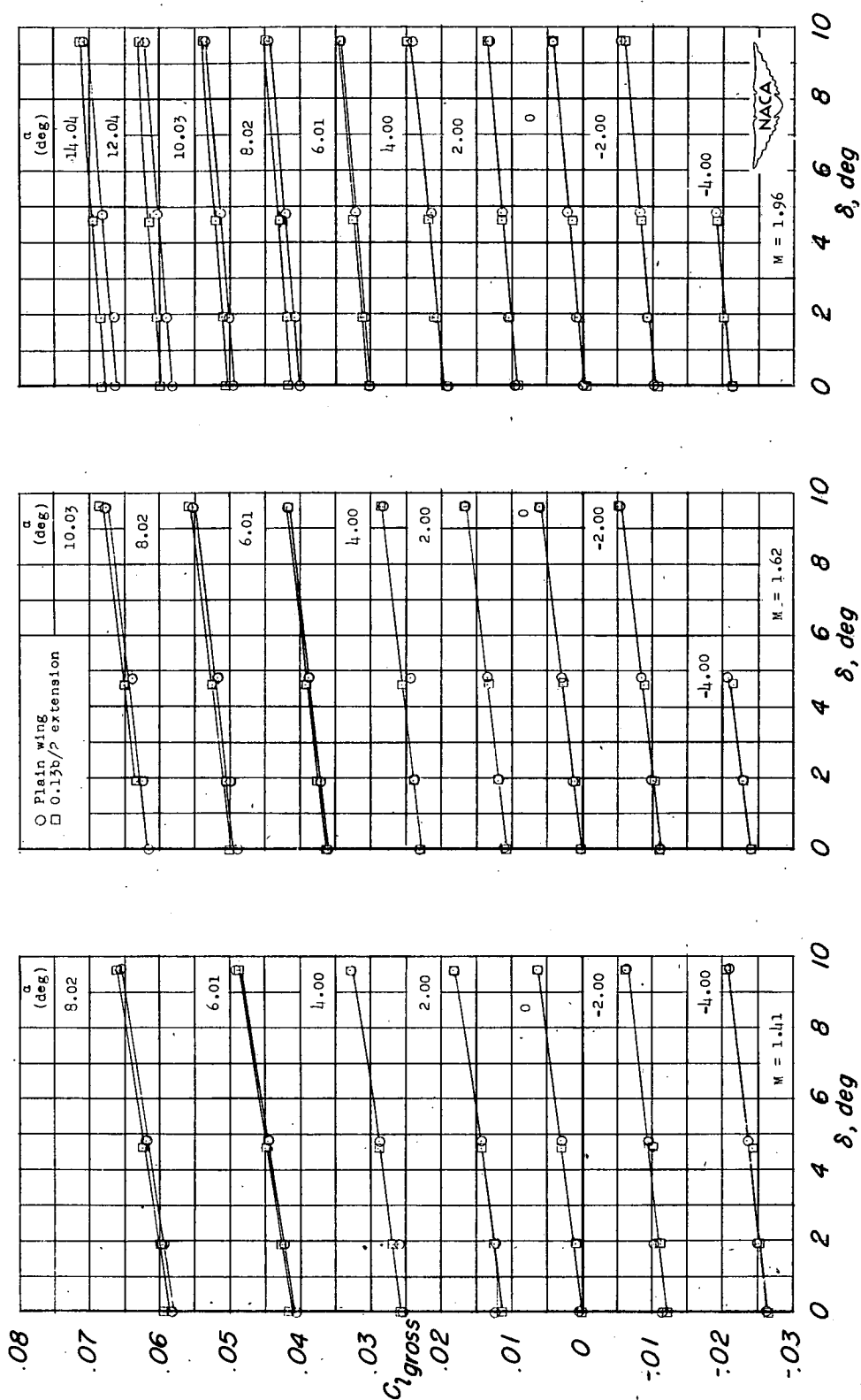
(b) Variation of $C_{l \text{ gross}}$ with δ .

Figure 6.- Continued.

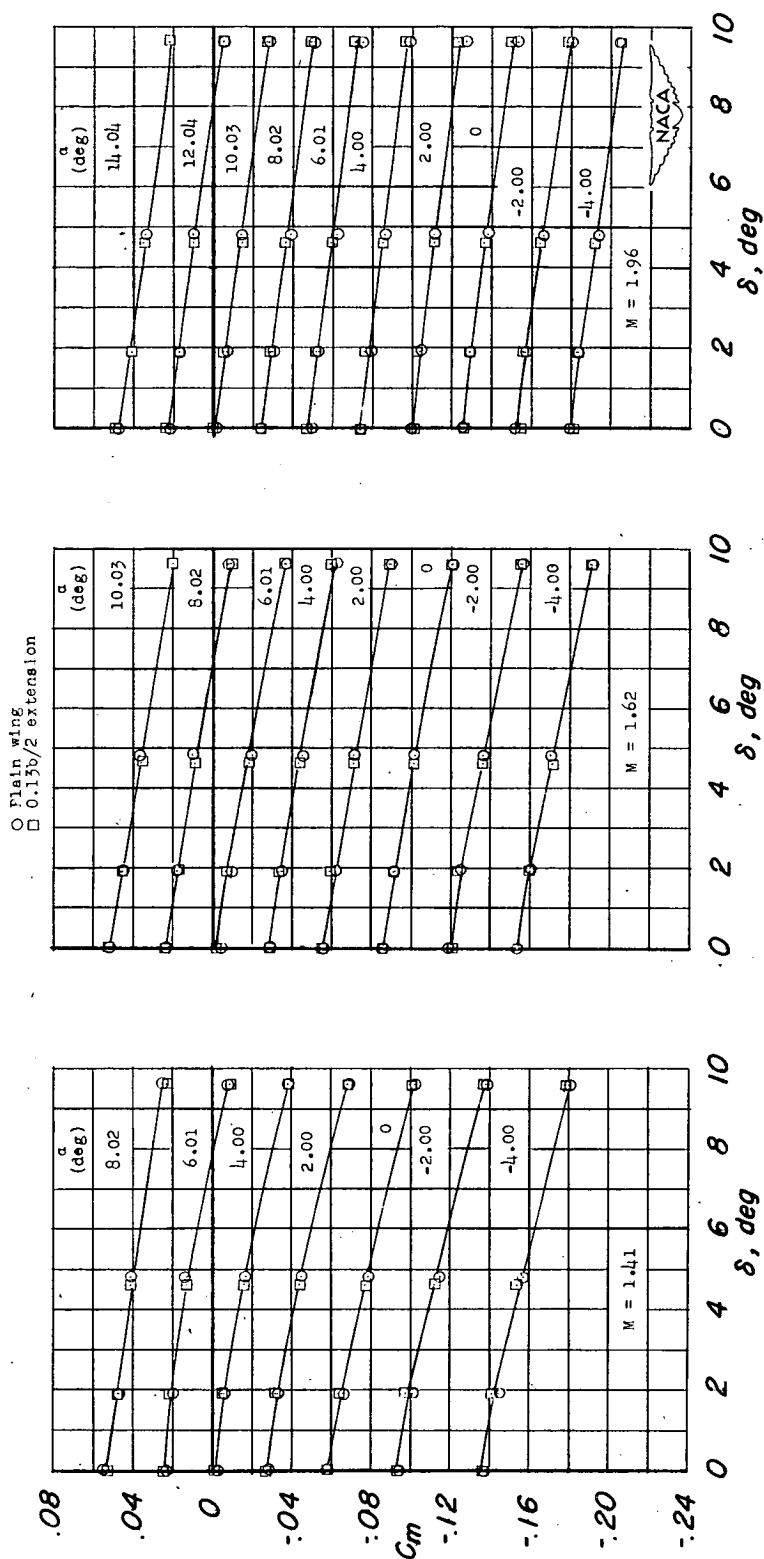
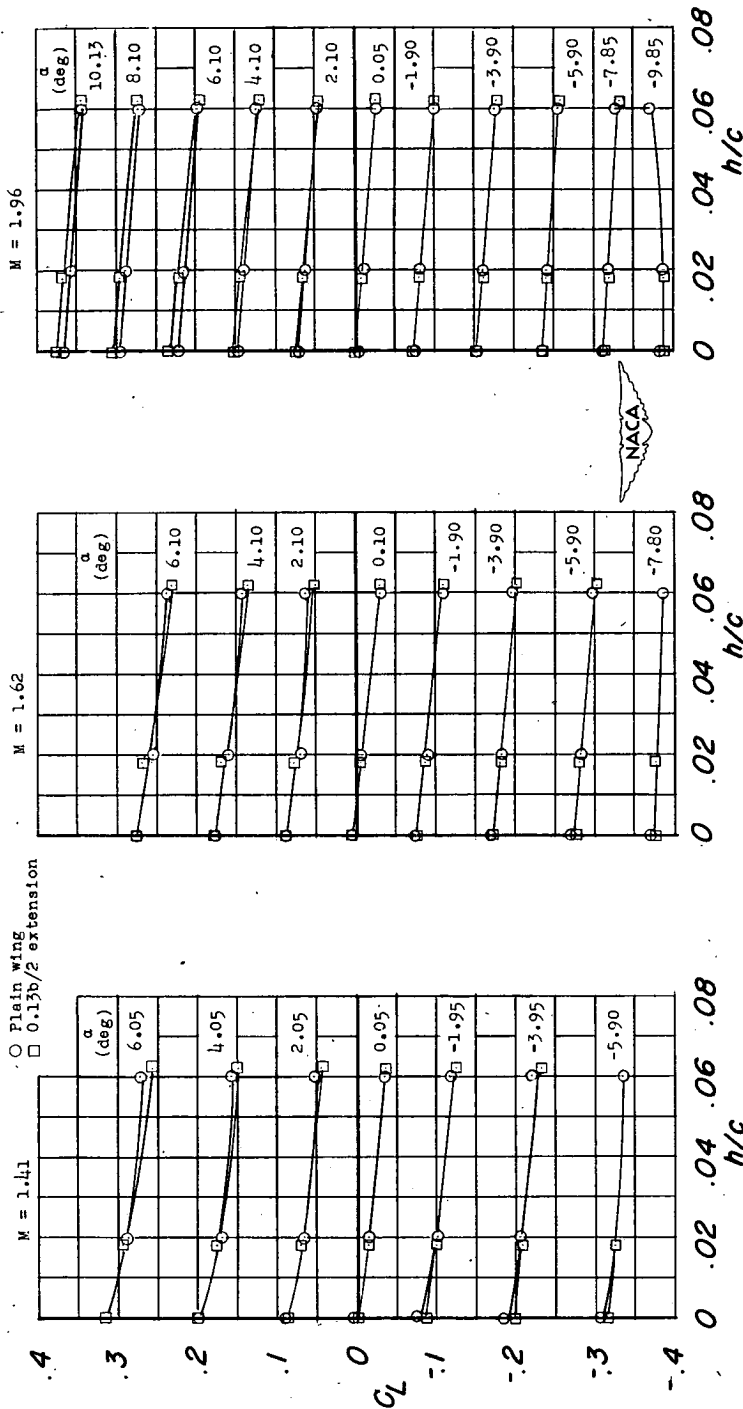
(c) Variation of C_m with δ .

Figure 6.- Concluded.



(a) Variation of C_L with h/c .

Figure 7.- The effects of a 0.13b/2 leading-edge chord-extension on the control characteristics of a 0.50b/2 spoiler-type control on a swept-back wing with biconvex airfoil sections. $M = 1.41$, 1.62, and 1.96; $R = 2.0 \times 10^6$, 1.8×10^6 , and 1.7×10^6 , respectively.

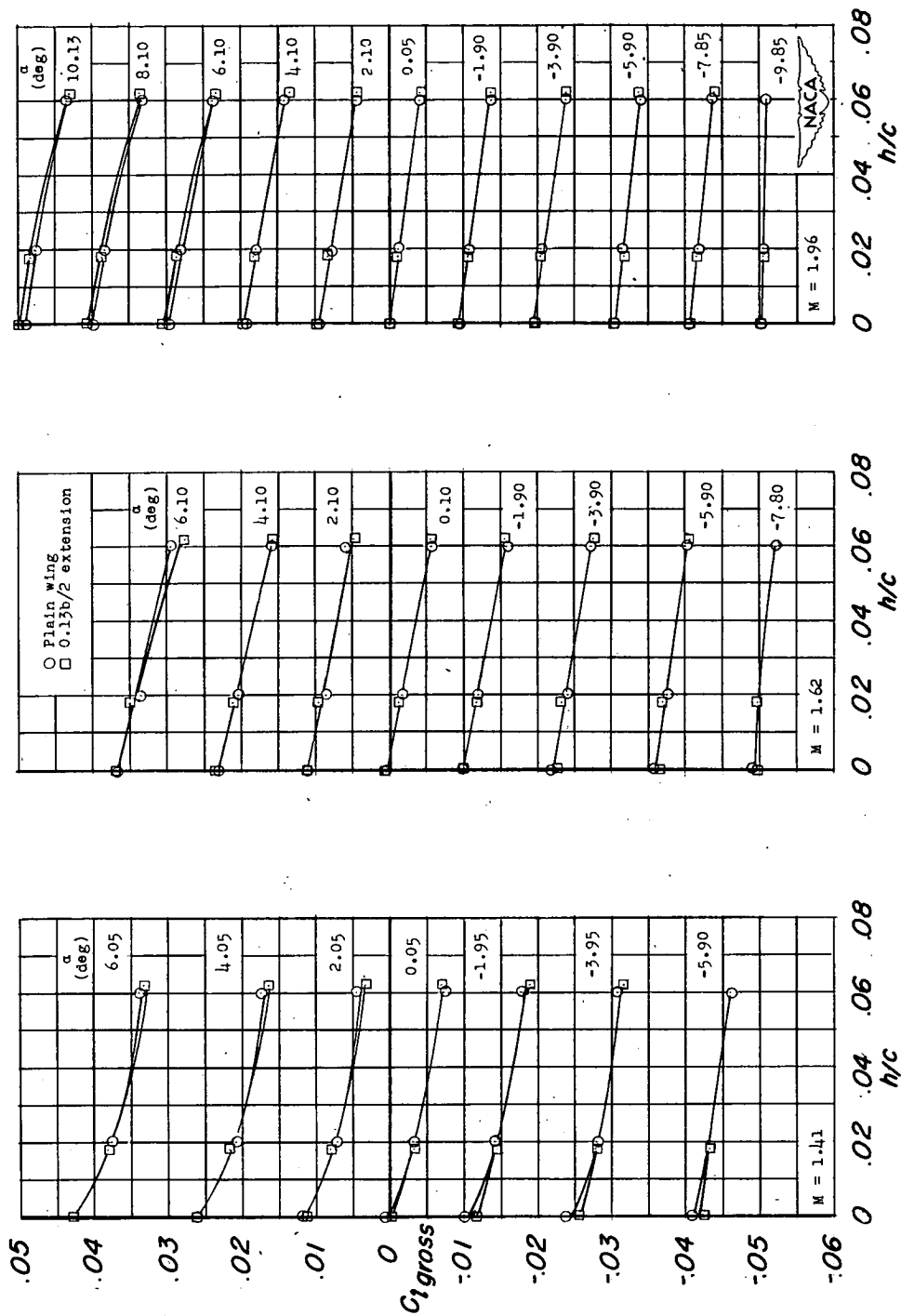
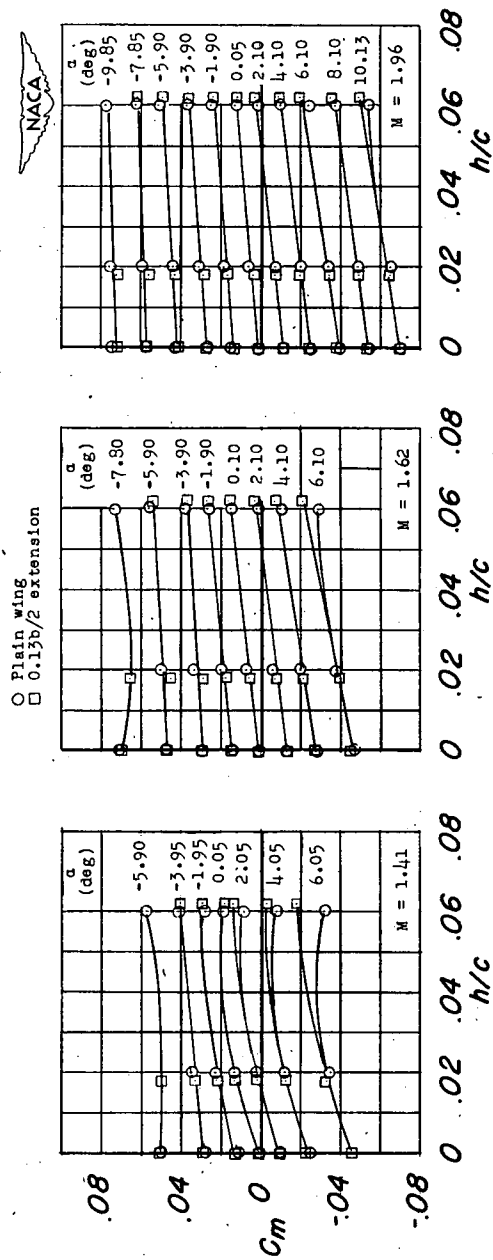
(b) Variation of $C_{l \text{ gross}}$ with h/c .

Figure 7.- Continued.



(c) Variation of C_m with h/c .

Figure 7.- Concluded.

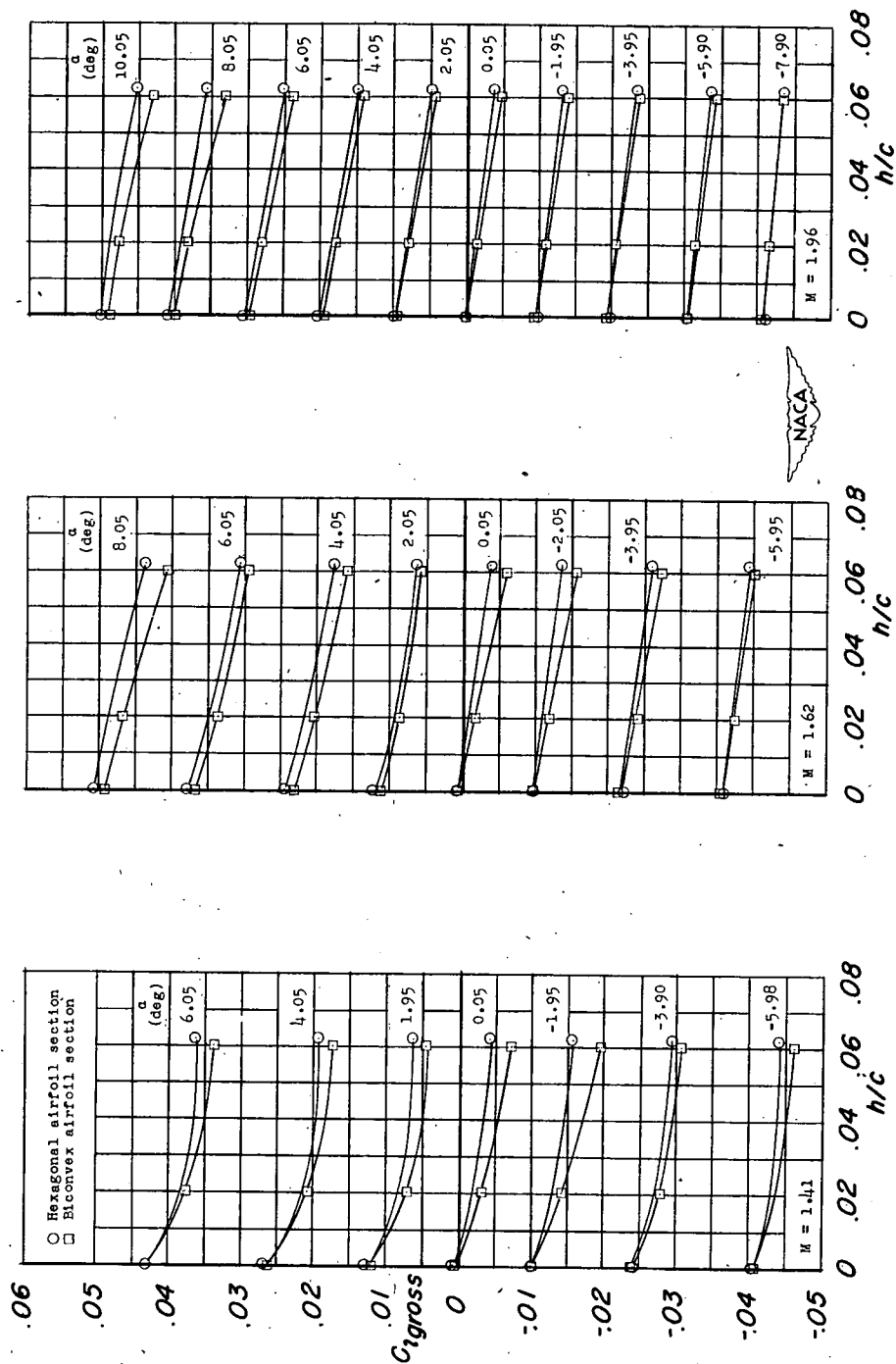


Figure 8.- Effects of airfoil section on the effectiveness of $0.50b/2$ spoiler-type controls on two sweptback wings; $M = 1.41$, 1.62 , and 1.96 ; $R = 2.0 \times 10^6$, 1.8×10^6 , and 1.7×10^6 , respectively.